Rapid prototyping of diffractive optical elements in microstructured sol-gel hybrid material

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Summary

TELECOM Bretagne and HOLOTETRIX Company fabricate diffractive optical elements in photoresist by direct-write through a reconfigurable mask. The project is to transfer microstructured patterns of photoresist element to sol-gel hybrid material. This material offers better properties than photoresist to make diffractive optics.

Introduction

Diffractive optical elements (DOEs) are currently gaining increased acceptance in the photonic industry in a wide range of applications such as laser beam shaping (e.g. in micromachining), information technology, telecommunications, medical and aerospace. DOEs can notably limit the loss of light, correct optical aberration and reduce the volume of an optical assembly. However, their more extensive use is often hindered by the barrier of high prototyping costs – cost advantages only appearing in mass production. We aim to reduce the entrance barrier to this technology by the development of rapid and simple prototype fabrication processes.

For laboratory prototypes, photoresist DOEs are widely used. They are simple to fabricate by parallel direct-write; this technique has chosen by TELECOM Bretagne and its spin-off company HOLOTETRIX. However, for many industrial applications the properties of photoresist are insufficient: optical (diffraction efficiency, resistance to high power laser beams), mechanical (hardness, durability and strength), thermal (stability) and chemical (resistance to usual cleaning solvents). To solve this problem, we have developed a process based on direct molding of a photoresist DOE in higher performance hybrid sol-gel material without the need for a time-consuming and costly nickel master.

Discussion

A DOE modifies the spatial distribution of a light beam by diffraction. The diffracted light creates several wavefronts which interfere and recombine to give the desired light distribution in the reconstruction plan. In our study, the DOEs [1] modify the phase of the lightwaves. In this case, the differences in optical path from one point to another of the DOE are produced by local variations of thickness in the material. The patterns created with thickness variations are calculated (digital algorithms) from the incident wave and the desired diffraction pattern.

In our laboratory, DOEs fabrication is accomplished by two main photolithographic techniques: 1. by direct light irradiation through a reconfigurable mask into photoresist (PR) and 2. by irradiation molding in a hybrid sol-gel material (HSG).

1. The first material is a commercial positive PR: SHIPLEY S1805 [2]. Its microstructuration is realized directly with a high speed parallel-write photoplotter at TELECOM Bretagne [1] operating at the wavelength of 436 nm (wavelength included in the visible absorption band of the PR). The photoplotter uses a liquid crystal micro-screen as a reconfigurable mask. The pattern on the micro-screen is projected onto the photosensitive using a high performance

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photoreduction lens. After development, the element is hardened by further UV illumination and final thermal treatment.

2. The second material is a HSG of the ORMOCER® family: Ormocomp [3]. This is a liquid photopolymer, which absorbs up to 400nm and can be cured at 365nm (peak emission wavelength of a mercury lamp). HSG, efficient for nanofabrication [4], can also be tailored for our project. We transfer the three-dimensional pattern of a photoresist DOE to the HSG by molding. A mask-aligner is used to control the contact and press both materials and to irradiate at 365nm for initiation of the HSG polymerization. After curing, PR and HSG are separated. HSG element is further processed (thermal treatment) to optimize its properties.

The replication process has been validated after analysis of the optical properties and comparison between microstructure of PR template and corresponding HSG copy. The patterns and the thickness layer measurements show high fidelity (Fig. 1).

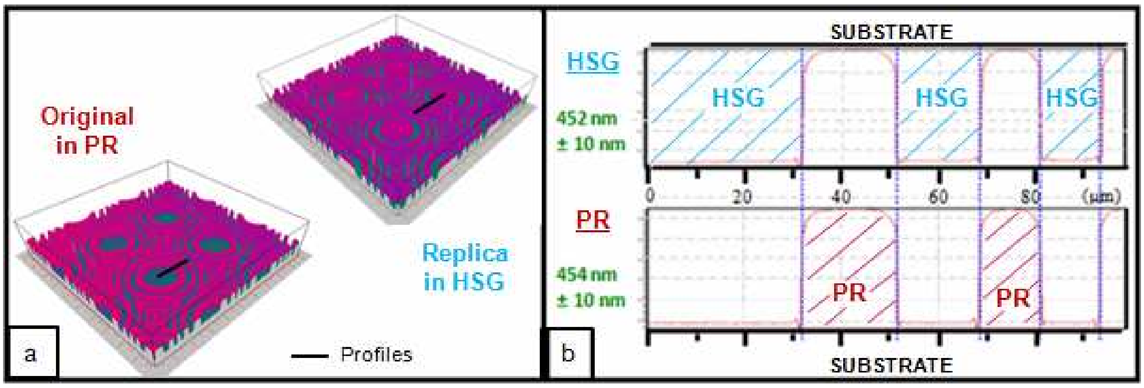

Fig 1**.** DOE pattern: 3D views (a) and profiles (b) performed by interferometric microscopy

The HSG material has a higher industrial performance than PR because it is a hybrid organic/inorganic material. The interest of the two-steps process is the use of HSG corresponding to a monomer combining a polymerizable function and a mineral part. The organic part enables microstructuration by photochemical means and the inorganic structure gives the final material glass-like properties. HSG offers better optical (transparency), mechanical (hardness, strength), thermal (stable up to 270℃) and chemical (resistance to usual solvents: acetone and isopropanol) properties compared to PR (stable up to 145℃, soluble in acetone and isopropanol).

Conclusion

The fabrication of HSG elements by direct molding from PR micro-patterns has been demonstrated and HSG shown to be a high-performance material for DOE fabrication. HSG is better suited to industrial requirements such as cleaning with usual solvents. The next steps concern the production of multiple replicas in HSG by micro-imprint with one HSG mold or by dicing a multi-DOEs substrate.

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